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## Bioremediation of Aromatic Hydrocarbons at Seal Beach, CA: Laboratory and Field Investigations

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by:

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The objective of this study was to develop our understanding of processes that are important in the anaerobic biodegradation of aromatic hydrocarbons in contaminated ground water aquifers. The focus of the investigation was a site at the Seal Beach Naval Weapons Station in Southern California where a significant gasoline spill resulted in contamination of the ground water aquifer. The project was divided into laboratory and field components which were interrelated. The goals of the laboratory experiments were to determine the capability of the aquifer microbial community to transform aromatic hydrocarbon compounds under various anaerobic conditions and to understand the effect of environmental factors on the transformation processes. Field experiments were carried out on site at Seal Beach. The objectives of the field experiments were to evaluate potential in-situ application of anaerobic bioremediation processes and attempt to apply laboratory results to the field. The results from the field experiment will be used to design a remediation proposal for the aquifer at the Seal Beach site.

### APPROACH and RESULTS

**Laboratory Study.** In a laboratory microcosm experiment, we evaluated several factors which were hypothesized to influence field-scale bioremediation. Individual monoaromatic compounds (e.g. benzene, toluene, ethylbenzene, and m-, p- and o-xylene) were the primary substrates. To test the influence of liquid phase composition on the hydrocarbon degradation potential of Seal Beach aquifer sediment, the sediment was placed in native ground water, native ground water with nutrient amendments, and in various other laboratory media formulations including denitrifying, sulfate reducing and methanogenic media. In replicate bottles during the first 52 d of the study, toluene and m+p-xylene (here, m-xylene and p-xylene were measured as a summed parameter) were biotransformed in the unamended ground water samples under presumed sulfate reducing conditions. Addition of nitrate to the ground water increased rates of toluene biotransformation coupled to nitrate reduction, stimulated biotransformation of ethylbenzene, and inhibited the complete loss of m+p-xylene that was observed when nitrate was not added and sulfate reducing conditions prevailed. Addition of the nutrients ammonia and phosphate had no effect on either the rate of aromatics transformation or the distribution of aromatics transformed. In contrast to nitrate amended ground water, ethylbenzene was always transformed first followed by toluene in the microcosms prepared with denitrifying media. In sulfate reducing media, lag times were increased but toluene and m-xylene were ultimately transformed just as in the microcosms with ground water alone. Although methane had been detected in the field, there appeared to be no transformation activity in the methanogenic microcosms during the period of the experiment.

**Bioreactor Study.** A pilot scale facility consisting of 90L reactors was constructed at the Seal Beach site. The facility was designed for the operation of three anaerobic in-situ bioreactors. The reactors consisted of aquifer sediment filled stainless steel cylindrical vessels with the capability to control and monitor both hydrodynamic flow and supplements to the composition of the native ground water influent. Initial operation of the three anoxic/anaerobic reactors focused on evaluating anaerobic bioremediation strategies for aromatic hydrocarbons under existing (presumed sulfate-reducing), and enhanced, denitrifying conditions.

Bioreactor results were consistent with the laboratory microcosm experiments. Toluene and m+p-xylene were degraded in both the unamended and nitrate amended bioreactors. Degradation of ethylbenzene was stimulated by nitrate addition. There was no evidence that benzene or o-xylene were transformed in either reactor. The final percentage removal efficiency appeared to be higher in the unamended bioreactor where flow was slower.

**Field Study.** Field experiments have been conducted to assess anaerobic bioremediation of a test zone within the contaminated aquifer at the Seal Beach site. A network of eight observation wells and one extraction well was installed at the Seal Beach site. Hydrodynamic evaluation of the well field indicated that two of the wells were satisfactory for further experimentation. Experiments have been conducted using a slug test experiment design in which a single well was used for the injection of the "slug" or test pulse and the same well was used to extract the test pulse. The results of the experiments were inferred by differences measured in the samples collected during extraction. Since the native ground water contained a variety of electron acceptors and the water used for the injected pulses was water which had previously been extracted from the test zone, the ground water was treated to control the concentration of all electron acceptors during the injection of the test pulse. Before injection, the desired salts were added back to the deoxygenated injection stream and the stream metered into the injection well. Sodium bromide was added as a conservative tracer. Under this scenario, the different electron acceptors investigated (e.g., nitrate and sulfate) could be added as desired. During initial tracer studies, the injection water was organics free, and thus the source of the organics was desorption from the in-situ aquifer solids. In subsequent and ongoing bioremediation studies, benzene, toluene, ethylbenzene, m-xylene, and o-xylene were added with the injection pulse at a concentration of approximately 200µg/L each.

The initial bromide tracer data showed stable tracer concentrations and indicated no substantial encroachment of native ground water detected in the first 0.4 pore volumes. There was a very small hydraulic gradient at the site, hence recovery of the bromide mass from the test wells ranged from 93 to 99 percent with the extraction of three pore volumes over a 103 day period. During the tracer test, the equilibrium desorption concentrations for the aromatic hydrocarbons when the electron acceptors nitrate and sulfate were absent from the ground water were evaluated. Benzene, ethylbenzene, and o-xylene concentrations remained relatively stable and thus appeared to be at an equilibrium. The toluene and m+p-xylene concentrations had a downward trend relative to benzene once the native ground water encroached after approximately 0.4 pore volumes suggesting that the nitrate and sulfate concentrations available in the native ground water supported some biological activity in the latter part of the experiment for toluene and m+p-xylene removal.

In a nitrate augmentation experiment, nitrate and aromatics were added to the injection pulse resulting in complete consumption of toluene and ethylbenzene followed by m-xylene within the first two weeks. o-xylene was slowly degraded and its concentration approached zero by day 60. There was no apparent loss of benzene when compared to the inert tracer. The addition of nitrate to the test region appeared to enhance the natural anaerobic denitrifying population. This would confirm that there was already an active nitrate reducing population in the aquifer whose activity was enhanced by the addition of nitrate. With the exception of o-xylene transformation, these results were comparable to those from the nitrate amended microcosm and bioreactor experiments wherein toluene, ethylbenzene, and m-xylene were transformed under denitrifying conditions.

During the tracer study, methane was detected in the test wells. With the encroachment of the native ground water and associated increase in nitrate and sulfate concentrations, the methane concentration decreased to values close to zero suggesting that nitrate and sulfate inhibit methanogenesis at this site.

Additional experiments are under way to determine more precisely some of the kinetic constants in the aquifer under denitrifying conditions and to evaluate rates and removal of aromatics under sulfate reducing and methanogenic conditions.

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